Expert Systems with Applications 41 (2014) 4170–4180

Contents lists available at ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

On-line signature verification using vertical signature partitioning

Krzysztof Cpałka, Marcin Zalasiński *

Institute of Computational Intelligence, Częstochowa University of Technology, Al. Armii Krajowej 36, 42-200 Częstochowa, Poland

ARTICLE INFO

Keywords:
Biometrics
On-line signature
Dynamic signature
Fuzzy sets theory
Neuro-fuzzy systems
Interpretability

ABSTRACT

In this paper we propose a new approach to identity verification based on the analysis of the dynamic signature. Considered problem seems to be particularly important in terms of biometrics. Effectiveness of signature verification significantly increases when dynamic characteristics of the signature are considered (e.g. velocity, pen pressure, etc.). These characteristics are individual for each user and difficult to forge. The effectiveness of the verification on the basis of an analysis of the dynamics of the signature can be further improved. A well-known way is to consider the characteristics of the signature in the sections called partitions. In this paper we propose a new method for identity verification which uses partitioning. Partitions represent time moments of signing of the user. In the classification process the partitions, in which the user created more stable reference signatures during acquisition phase, are more important. Other important features of our method are: using capabilities of fuzzy set theory and development on the basis of them the flexible neuro-fuzzy systems and interpretable classification system for final signature classification. In this paper we have included the simulation results for the two currently available databases of dynamic signatures: free SVC2004 and commercial BioSecure database.

1. Introduction

Signature is a biometric attribute used to verify identity of the individual. It belongs to the behavioural biometric attributes which are related to the pattern of behaviour of a person. Verification based on these attributes is more difficult than verification based on the physiological ones, but this process is less invasive than verification with use of the physiological attributes (e.g. fingerprint, iris). Moreover, signature is very interesting behavioural attribute which is commonly accepted in the society. Thus if the effectiveness of verification systems based on the signature is high enough, they may be used for commercial purposes, for example as the access verification systems to the workplace or as the systems supporting identity authentication in banks. Moreover, they may replace many commonly used methods of authorization, e.g. password authorization, PIN code authorization. Disadvantage of these traditional methods is possibility of forgetting or losing password or PIN code. The use of dynamic signature in authorization process eliminates these dangers.

Signature verification systems may be classified into two categories – static (off-line) and dynamic (on-line). Systems using off-line work on the basis of information about the shape of the signature and can use, for example, signatures from documents in verification process. Systems using on-line signature during verification can use also information about dynamics of the signing process, e.g. pressure. In this case the shape of the signature is represented by the horizontal and vertical trajectories. Identity verification based on the on-line signature is more reliable than verification using the off-line signature, because the dynamic features make the signature more unique and more characteristic for the individual.

Approaches to identity verification based on dynamic signature may be categorized into few groups:

– **Global feature based methods.** Some methods base on the global features which are extracted from signature and used during training and classification phase. Examples of these features are signature total duration and number of pen-ups. Approach based on global features may be found in many research papers. In Nanni and Lumini (2005) authors have proposed method of signature verification based on the ensemble of Parzen window classifiers. In Nanni and Lumini (2006) system based on two-class problem is presented. The system uses Support Vector Machine to classify vector of signature global features as genuine or forgery. In Nanni (2006a) method using combination of two-class classifier and one-class classifier is proposed. Fusion of the classifiers is realized using the radial basis function-support vector machine. In Lumini and Nanni (2009) algorithm for building an ensemble of on-line signature verification systems based on one-class classifiers and using "artificial features" is shown. These features are extracted with use of so called OverComplete global feature combination, and a small subset of features used during classification is selected by sequential

* Corresponding author. Tel./fax: +48 343250546.
E-mail addresses: krzysztof.cpalka@iisi.pcz.pl (K. Cpałka), marcin.zalasinski@iisi.pcz.pl (M. Zalasiński).

0957-4174/$ - see front matter © 2014 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.eswa.2013.12.047

forward floating selection. In Fierrez-Aguilar, Nanni, Lopez-Penalba, Ortega-Garcia, and Maltoni (2005) authors have proposed a set of features sorted by their individual discriminative power for the group of signers. The best results achieves fusion of classifier based on Principal Component Analysis method and Parzen window classifier.

- **Function based methods.** Another approach commonly used in identity verification based on dynamic signature is function-based approach. This approach bases on comparison of time functions, which contains information about changes of signature features over time. Time functions extracted from the signature are compared to the time functions of the other signature and classification is made on the basis of this process result. Comparison is performed using elastic distance measures, e.g. Dynamic Time Warping (see Jeong, Jeong, & Omitaomu, 2011). In this approach one can use time functions acquired during signing process on the digital tablet (e.g. x-trajectory, y-trajectory, pressure), their derivatives (velocity, altitude) or combinations (difference between the values of two consecutive points of x-trajectory or y-trajectory). In Jain, Griess, and Connell (2002) authors have proposed verification based on the set of features computed for each discretization point. This set contains features which describe shape of the signature and the ones based on dynamics of the signing process. In Kholmatov and Yanikoglu (2005) classification based on the distances of the test signature to the nearest, farthest and template reference signatures, stored in a three-dimensional feature vector, was presented. The distances are computed by Dynamic Time Warping algorithm and the feature vector is classified into one of the two classes (genuine or forgery) by classifier based on Principal Component Analysis. In Faundez-Zanuy (2007) classification by combination of vector quantization and Dynamic Time Warping was presented. The combination is performed by means of score fusion. In Nanni and Lumini (2008) dynamic signature verification system based on the Linear Programming Descriptor classifier was presented. In this method the time functions extracted from the signatures are transformed by discrete 1-D wavelet transform and next the Discrete Cosine Transform is used to reduce the approximation coefficients vector to a feature vector of a given dimension. In Maiorana (2010) author has presented function based system with use of cryptographic techniques to provide protection and cancelability to signature templates.
- **Regional based methods.** The literature contains also approaches relying on segmentation of signature into some regions, which are used during training and verification phase. Methods based on regional information of signature use often classifier based on Hidden Markov Models (see e.g. Fierrez, Ortega-Garcia, Ramos, & Gonzalez-Rodriguez, 2007). Many authors propose also different methods of classification. In Huang and Hong (2003) signatures are segmented into strokes and for each of them reliability measure is computed on the basis of the features values which belong to the current stroke. In Khan, Khan, and Khan (2006) a stroke-based algorithm that splits velocity signal into three bands was proposed. This approach assumes that low and high-velocity bands of the signal are unstable, whereas the medium-velocity band is useable for discrimination purposes. In our previous works we have also considered a method from regional based methods group (see Zalasiński & Cpałka, 2011, 2012, 2013). The idea of this method was consideration of signature areas characteristic for each user. These areas (known as horizontal partitions) were associated with high and low velocity of signature, and a low and a small value of pen pressure.
- **Hybrid methods.** In the literature one can also find the hybrid methods which are based on combination of the described approaches. For example in Nanni, Maiorana, Lumini, and Campisi (2010) system for dynamic signature verification based on an ensemble of local, regional, and global matchers was presented. The system uses fusion of two methods employing Dynamic Time Warping, a Hidden Markov Model approach and a Linear Programming Descriptor classifier trained by global features. In Moon, Lee, Cho, and Kim (2010) authors have presented system based on combination of global features based methods and function based methods. Feature based module calculates the distance between the multi-dimensional vectors of reference signature and test signature. Function based module calculates the accumulated distance between input time of reference signature and test signature. Next, calculated distances are combined in accordance with an appropriate form.

In this paper we propose new method for the on-line signature verification based on partitioning. The method belongs to the regional based methods group and it bases on partitioning of waveforms which describe the signature. The idea of partitioning has been considered in the literature:

- In Ibrahim et al. (2010) authors have proposed a very interesting and effective algorithm. It assumes using in classification process vertical and horizontal trajectories of signature which lies in the regions of it, extracted on the basis of the values of pressure and velocity signals. The regions of signature are called partitions. After division of signature trajectories into partitions, the template which represents information about the signer is created for each partition on the basis of the training signatures. Next, selection of the most discriminative partition (called stable partition) is performed. Stable partition is selected on the basis of similarities between each training signature of the user and the template. The template from selected partition is used during verification process to determine whether the test signature of the user is true or not.
- In our previous work Zalasiński and Cpałka (2012) we have proposed a new algorithm for dynamic signature verification using horizontal partitioning. Partitions corresponded to high and low velocity of the signature and high and low pressure. For each user partitions and importance of them in the classification process were selected individually. This allowed for more efficient verification of identity. On the basis of this method the method proposed in Zalasiński and Cpałka (2013) was created, which is characterized by interpretability of the signature classification process. Using that methods (differ in the way of final classification) we obtained a very good accuracy and come to some interesting conclusions. It turned out that in the classification of dynamic signature more important role than pressure signal plays velocity signal, and more characteristic for the users were these areas of the signature, which were created at a higher speed and larger pen pressure. The results of simulations encouraged us to continue to use the idea of partitioning in the process of signature verification. The method proposed in this paper also uses partitioning, but it is decisively different from our previously proposed methods. This is due to the fact that in this paper partitions have a completely different interpretation and represent time moments of signing by the user.

It should be noted, that the method proposed in this paper is characterized by important advantages over other methods available in the literature which use partitioning of dynamic signature. These advantages include, among others, use of the partition importance in the classification process of dynamic signature, interpretability of knowledge acquired in the classifier of the signature and using the abilities of fuzzy sets and fuzzy systems in the signature classification. The combination of these characteristics